IN-PLANT NOISE EXPOSURE MANAGEMENT FOR AN INDUSTRIAL PROCESS AIR SYSTEM

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INTRODUCTION

At the NASA Lewis Research Center in Cleveland, Ohio, experimental research in aircraft and space propulsion systems is conducted in more than 100 testing facilities and laboratories, including large wind tunnels and engine test cells. A central process air system supplies these cells or test facilities with high-volume, high-pressure compressed air and vacuum at various conditions that simulate altitude flight. The processed air is provided by a variety of large mechanical equipment located primarily in a Central Air Equipment Building (CAEB). Conditioned air is routed to test cells through a complex distribution network of piping, remotely operated and controlled by computer.

The Central Air Equipment Building is part of a complex that houses a large number of pieces of equipment, including six compressors and eight exhausters as well as turboexpanders, heaters, chillers, dehydrators, and other auxiliary pieces of equipment. Much of this equipment was installed prior to the enactment of legislation limiting product noise emissions or occupational noise exposure. Continuous equipment monitoring and field maintenance are performed in this high-noise environment by a full-time staff of operators working to support three-shift research testing. The large volume and acoustically reflective interior surfaces of the building magnify the multiple noise sources into a noise exposure environment for which effective engineered controls are not economically feasible. The extremely high sound level also hinders face-to-face communications for personnel working in the building and complicates radio communications between field operators and remotely located dispatch personnel.

In the absence of feasible engineered controls, strong emphasis has been placed on personal hearing protection as the primary mechanism for assuring compliance with the Occupational Safety and Health Administration (OSHA) standard on occupational noise exposure, 29 CFR § 1910.95, which mandates a maximum daily Time Weighted Average (TWA) exposure of 90 dB(A), as well as NASA's more conservative policy, which requires that personal hearing protection reduce noise to 85 dB(A) (or, if this is not possible, to a TWA of 85 dB(A)).

Unfortunately, the use of hearing protection further hinders communication between personnel, and its effectiveness has often been compromised to meet operational demands.

To date, efforts to address the requirement for safety and clarity of communications have resulted in the establishment of noise-attenuating enclosures conveniently located within the plant. The enclosures reduce noise to acceptable levels that permit direct and radio communication and also provide operators occasional relief from the noise as operations permit. The accessibility of the enclosures discourages employees from removing hearing protection in high-noise areas of the plant, thus eliminating the most severe contributions to noise exposure for the operations staff as well as for transient maintenance and construction contractors.

PERSONAL NOISE DOSIMETRY STUDY

The recent identification of two cases of Standard Threshold Shift (STS) among the operations staff (as well as two cases among the staff of a similar process air plant) motivated a personal noise dosimetry study to characterize noise exposures and clarify hearing protection requirements. Members of the CAEB operations staff participated in the study, undertaken primarily to verify compliance with 29 CFR § 1910.95 and to provide a quantitative basis for a simple, flexible, and time-independent policy to govern the wearing of personal hearing protection at CAEB. A secondary objective of the study was to identify and prioritize significant noise sources for which engineered controls could be considered.

As many as four employees per shift were fitted with Larson•Davis NoiseBadge™ 705 programmable dosimeters that were worn for the duration of the shift. Employees recorded their approximate location in the plant (main floor, basement, turboexpander area, or "quiet" area) to the nearest five-minute time period. During a three-week period, forty-one data files were accumulated, of which 30 were determined during initial analysis to accurately reflect realistic operating conditions. Nine files were selected for detailed analysis by meeting one or more of the following criteria:

1. A high TWA exposure was recorded.

2. The file represents a typical high-noise job assignment.

3. A large number of pieces of equipment were in operation.

4. Specific pieces of known high-noise equipment were in operation.

Each dosimeter data file of five-minute A-weighted sound levels was merged with the corresponding logs of employee location and equipment operation into a spreadsheet. The nine individual files were combined into one composite file to allow time-independent analysis of Leq sound levels in the three high-noise areas of the plant (main floor, basement, and turboexpander area). Representative values of instantaneous A-weighted sound level for each of these areas were determined for the purpose of developing area-specific hearing protection requirements for employees not permanently assigned to the plant. Measured 8-hour TWA exposures were also analyzed to support the development of a TWA-based policy for the operations staff.

RESULTS

Dependence of A-weighted sound level on equipment operating condition. Neither five-minute Leq nor Max A-weighted sound levels in the nine selected files demonstrated any significant dependence on number of total pieces of equipment in operation or on any particular combination of equipment. Expanding the analysis to include the remaining 21 dosimetry files, which generally represent conditions with fewer pieces of equipment in operation, could be expected to illuminate some dependence of sound level on operating condition. The results obtained from the limited analysis can be partly attributed to the reverberant environment in the building as well as to the spatial variation in sound level within each of the three high-noise areas, even for a particular operating condition.

Representative sound levels for high-noise areas. The results of a statistical analysis of A-weighted Leq sound levels for all operating conditions are shown in Table 1 for each area. Average and maximum values are tabulated, along with levels exceeded by 10% of the data. Tabulated statistics for main floor, basement, and turboexpander area are based on data acquired during equipment operations. The remaining column, included for completeness, describes the cumulative time spent anywhere in the plant during non-operating periods and in office and break areas during operations but does not accurately describe sound levels in any specific area of the plant.

Table 1.
Statistical Analysis of Five-Minute A-Weighted Leq Sound Level

	Leq Sound Level, dB(A) n = number of data samples			
	Main Floor n = 176	**Basement** n = 160	**Turboexpander Area** n = 50	**Quiet Areas** n = 478
Average	95	107	107	84
Maximum	117	125	115	111
90th percentile	106	120	112	97

Representative TWA noise exposure for equipment operators. Average and maximum TWA values for the nine data files are shown in Table 2 as well as a composite TWA based on five-minute Leq data from all nine files.

Table 2.

Representative Values for 8-Hour (TWA) Noise Exposure for Equipment Operators in CAEB	
	TWA, dB(A)
Average TWA for nine data files	101
Maximum TWA for nine data files	109
Composite TWA calculated on nine combined files	103

Resulting sound levels and TWA exposures with hearing protection. Resulting sound levels and TWA exposures with hearing protection are shown in Table 3 for each of the personal hearing protectors in use at CAEB at the time of the dosimetry study. Sound levels are based on the 90th percentile A-weighted Leq sound level for each high-noise area from Table 1. TWA exposures for the operations staff are based on the composite (nine-file) TWA from Table 2. Reviewing Table 3 indicates that, for most protectors and in most areas of the plant, the limit of 85 dB(A) TWA specified in NASA's policy is exceeded by 8-hour exposure. Despite the use of high-quality hearing protection, 8-hour exposures to sound levels in the basement exceed OSHA's limit of 90 dB(A) except for dual protection (wearing earplugs together with muff-style protectors).

Table 3.
Resulting Sound Levels and TWA Exposures With Hearing Protection for CAEB High-Noise Areas and Operations

Protector Description	NRR	Sound Level, dB(A)			Operator TWA, dB(A)
		Main Floor	Base-ment	Turbo Area	
Hard hat muff attachments	24	89	103	95	86
Communication headset	24	89	103	95	86
Muff-style protector	29	84	98	90	81
Self-expanding foam plugs	32	81	95	87	78
Foam plugs with muffs	37	76	90	82	73

A hearing protection policy for CAEB that meets OSHA's noise exposure limits will provide employees the greatest flexibility in hearing protector selection and will accommodate operational considerations to the maximum extent possible. In conjunction with this policy, an aggressive program has been implemented to lower noise exposures to 85 dB(A) by upgrading the accessibility and quality of "quiet" areas within the plant and by implementing selected engineered controls over a period of time.

OPERATIONAL CRITERIA FOR A HEARING PROTECTION POLICY

The variety of noise exposure scenarios among maintenance, construction, and operations personnel and the particular requirement for radio communications capability among the operations staff has resulted in the development of a comprehensive policy governing personal hearing protection requirements for CAEB. The policy, while accommodating numerical data obtained via the dosimetry study, is based on the following guidelines to maximize the degree to which it is understood, implemented, and accepted and to minimize the negative impact on operations:

1. The policy must be simple. Hearing protection requirements that are based on the assumption that employee noise exposure is limited (less than 8 hours) in duration are difficult to understand. Implementation of such a policy is impractical, and enforcement is difficult unless the employees' activities (and, therefore, noise exposures) are uniform and fairly consistent from day to day. For administrative simplicity, hearing protection rules for specific areas must be based on the assumption of 8-hour exposure to the noise level in that area. This requires that the protector have a sufficiently high rating to reduce noise to 90 dB(A). (It is safe to assume that sound levels (noise exposures) in the CAEB complex represent an upper bound on what would be encountered by employees who spend part of a work shift in other high-noise facilities.)

2. The policy must not rule out the use of hard hat muff-style attachments, which have a Noise Reduction Rating (NRR) of 24. Hard hats, which preclude wearing higher-rated

muff-style protectors, are required at all construction sites (construction projects are common in the main floor and basement areas but are rare in the turboexpander area). Employees who are required to wear hearing protection must wear either earplugs or muff-style attachments for the hard hat. Muff-style attachments are popular among employees and are easy to use.

3. Whenever possible, the policy must allow alternatives to self-expanding foam earplugs. Self-expanding foam earplugs, while providing a high NRR, are often inserted incorrectly by employees who do not use them often or who have not been trained in their use. In addition, earplugs are known to aggravate some medical conditions, and hygiene concerns limit the use of plugs in some work environments.

4. The policy must accommodate the use of radio communication headsets (NRR = 24), which are worn much of the time by operations personnel. Furthermore, it is impractical and can be dangerous to wear earplugs (presumably to increase the NRR) while wearing communication headsets.

5 Dual protection (wearing plugs together with muff-style protectors to increase the effective NRR) should be required as infrequently as possible. The wearing of dual hearing protection is cumbersome, difficult to enforce, and unpopular among employees.

6. The policy should accommodate existing hearing protectors and established practices as much as possible. Many employees have a strong preference for a particular style of protector. High-rated muff-style protectors and plugs are available to employees, and their use in the CAEB complex has been equally encouraged. All operations personnel and most other permanent employees have their own muffs, and earplug dispensers are located throughout the complex.

PERSONAL HEARING PROTECTION POLICY FOR CAEB

The following policy includes a TWA-based standard that addresses the unique requirements of the operations staff, whose work is limited to the CAEB complex and whose noise exposure is fairly consistent. It also provides a separate standard comprising area-specific rules that cover casual building traffic, including engineers, managers, vendors, inspectors, and visitors as well as construction and maintenance personnel who support discrete projects of varying durations and who may also have other sources of occupational noise exposure on any given day.

Hearing protection options based on TWA exposures (operations staff). Hearing protectors with a rating of NRR = 24 or better will satisfy OSHA's requirement for the operations staff, whose TWA noise exposure is routine, consistent, and well understood. Considering that the operators wear better quality (higher-NRR) hearing protection whenever communication headsets are not required, it is likely that their exposures (with protection) also satisfy NASA's policy, which is equivalent to OSHA's for employees with STS.

Hearing protection options based on 8-hour exposure to A-weighted area sound levels (all other employees and visitors). All hearing protectors in Table 3 will meet OSHA's limits for 8-hour exposure to sound levels measured on the first floor of CAEB. For work in the turboexpander area, muff-style protectors or self-expanding foam plugs will allow 8-hour exposure within the OSHA limits.

Dual hearing protection will accommodate 8-hour exposure to sound levels in the basement at a level (with hearing protection) of 90 dB(A), based on an instantaneous A-weighted sound level of 120 dB(A). Although this 90th percentile level is severe, sound levels in the basement do vary considerably with operating condition. As a flexible and practical alternative to implementing an unconditional requirement for dual protection in the basement, a requirement that is based on actual measured sound level would limit the (mandatory) use of dual protection and allow employees more choices in hearing protector selection at lower sound levels. One workable solution would allow all hearing protectors in Table 3 to be worn in the basement when measured sound levels did not exceed 110 dB(A) (based on a realistic 6-hour total daily exposure that accounts for lunch, breaks etc.). Such a procedure can be implemented with the installation of a sound level detector system that would activate illuminated caution signs (requiring dual protection) when the sound level in the basement exceeds 110 dB(A).

CONCLUSIONS

The results of the dosimetry study indicated that all hearing protectors listed in Table 3 may be worn anywhere in CAEB by the operations staff, whose TWA noise exposures are routine and consistent. All protectors in Table 3 may also be used by other employees and visitors on the main floor of CAEB and will meet requirements of 29 CFR § 1910.95 for use in the basement when the sound level does not exceed 110 dB(A). Dual hearing protection is required in the basement whenever the A-weighted sound level exceeds 110 dB. Muff-style protectors or self-expanding foam plugs are recommended for the turboexpander area. The following actions will facilitate the implementation of this policy and insure that it is understood and consistently followed:

1. Install sound level detector systems in basement and main floor areas of CAEB that activate illuminated caution signs when the A-weighted sound level reaches a designated level. Main floor signs will indicate the requirement for hearing protection at 85 dB(A), while signs located at the entrances to the basement will indicate the need for dual protection when the A-weighted sound level in the basement exceeds 110 dB. All protectors in Table 3 are acceptable for use in the basement when the sign is not illuminated.

2. Continue to pursue upgrades to the quality (NRR) of hearing protection that may be worn by operators who require radio communication capability. Higher-rated muff-style communication headsets are being investigated, as are alternate communication systems (e.g., headsets that employ bone conduction and, therefore, permit the wearing of best-quality hearing protectors).

3. Implement engineered controls (pipe lagging, quiet valves, etc.) that will reduce the A-weighted sound level in the basement to the maximum extent possible.

4. Begin to employ acoustic emissions specifications when purchasing new equipment for CAEB. This will prevent any increase in A-weighted sound levels, which should decrease over time as equipment is replaced.

5. Reduce employee exposure to basement noise levels where possible by scheduling maintenance and construction activities to coincide with periods of lighter operations.

6. Encourage the use of self-expanding foam plugs (highest rated protector available) in the basement, and increase awareness of proper insertion techniques among construction and maintenance contractors who do not typically attend hearing conservation training classes offered through the Lewis Research Center's Hearing Conservation Program.

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